ARGUMENT

FOR THE

COMPLAINANT,

IN THE CASE OF

The State of Pennsylvania,

VS.

The Wheeling and Belmont Bridge Company,

IN SUPPORT OF THE COMMISSIONER'S REPORT UPON THE NECESSITY AND UTILITY OF THE STEAM PACKET CHIMNEYS NOW USED ON THE OHIO RIVER.

IN REPLY TO MR. RUSSELL,

BY

GEORGE HARDING.

WASHINGTON.
1851.

IN THE SUPREME COURT OF THE UNITED STATES.

The State of Pennsylvania,
vs.
The Wheeling and Belmont Bridge Company. } In Chancery.

ARGUMENT FOR COMPLAINANT.

The commissioner to whom this case was referred, having reported in favor of the utility of high chimneys as a mode of procuring the furnace draft required by steamboats navigating the Ohio river, it is intended in this argument briefly to set forth a few considerations in support of his views on that question, in reply to an argument on file controverting the positions taken by the commissioner.

It was shown in evidence before the commissioner, and appears in the proofs returned by him to this court, that there were, at and previous to the time of his appointment, certain steamboats, trading between Pittsburg and Cincinnati, which were furnished with chimneys or smoke pipes, varying in vertical height, from the top of the boilers, from fifty-seven to sixty-six feet. That these chimneys, when placed in their position on the boilers, were so elevated, that their tops were at the height of from sixty-six to eighty-four feet above the level of the water. That there were smaller boats than the above, the height of whose chimneys, from the surface of the water, varied from fifty to sixty feet. That all of these boats were, in their daily course of navigation, obliged to pass along the Ohio under the Wheeling bridge, and that the space, between the bridge and the surface of the water, was not sufficient to allow many of these boats to pass.

It was contended, on behalf of the defendants, that these chimneys were unnecessarily high, because,

1. Scientific principles indicated that a lower height was amply sufficient for the required purposes of those boats.

2. That the practical experience of other places than Pittsburg had demonstrated such height of chimney to be unnecessary.

3 That admitting such height of chimney to be necessary, there were ordinary and convenient substitutes for high chimneys which could, without disadvantage to said boats, be used.

It is believed that the above enumeration comprises all the points contended for in the evidence offered before the commissioner on behalf of the defendants. To support these positions on the one side, and to controvert them on the other, the defendants submitted the testimony of Professor Bartlett, of West Point, as a scientific expert, and the testimony of boat and engine builders, and captains of New York, Cincinnati, Wheeling, and Louisville, as practical experts; and the complainants submitted the testimony of Professors Renwick and Byrne, of New York, Professor Locke, of Cincinnati, and Colonel Long, of the United States engineer corps, as scientific experts, and the testimony of numerous practical experts of the same character, and resident at the same places as those offered by the defendants. In the testimony of all the scientific and practical experts there is no substantial difference.

The commissioner and his engineer visited and inspected the boats in controversy, and, upon the testimony furnished by the professors of science, the practical experts,

and his own observation, he decided against the several above-mentioned positions taken by the defendants, and reported that the bridge was an obstruction to the free navigation of the Ohio by steam vessels.

Before entering upon the particular examination of the above positions, it may not, perhaps, be deemed irrelevant briefly to explain what we conceive to have been the scientific and practical principles involved in this branch of the case.

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PRINCIPLES OF COMBUSTION AND DRAFT.

The generation of the steam, to propel these steamboats, is effected by the combustion of bituminous coal. Every combustion of fuel may be regarded as the phenomenon by which the oxygen of the atmosphere is caused to combine with such fuel and develope heat. The conditions requisite to the existence of this phenomenon are, the presence of fuel in a heated state, in contact with a constant supply of air. To secure this constant supply of air, two modes are adopted in practice. *First*, by attaching to the furnace or fire-place, in which the combustion is to be carried on, a vertical tube, called a chimney, in which air may be rarified by the action of the fire itself; and, *second*, by employing certain mechanical contrivances by which a current of air may be forced through the fire. In the first instance, a supply of air is forced through the furnace or fire-place by the pressure of the surrounding atmosphere, and in the second instance by the mechanical force of a bellows, a rotating fan, &c.

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THE MODE OF EFFECTING COMBUSTION BY A CHIMNEY.

If a vertical tube, of any height, and open at both extremities, be placed so that its lower extremity shall be above or in communication with the upper part of a heated mass of fuel, the air contained in such vertical tube will become heated, and therefore rarified, and will be lighter than a corresponding column of atmosphere outside of the chimney. The relative gravity of the surrounding atmosphere will cause it to enter into the lower extremity of the chimney and force the light air contained therein to rise, in the same manner that the relative gravity of the atmosphere forces a balloon to rise.*

If the furnace be so connected with the chimney that the air, in entering the lower part of the chimney, must pass through the heated fuel, it is evident that the supply of air, for combustion, will be obtained. The quantity of air that will be forced into the fire, and the velocity with which such air will tend to be forced through the chimney, are such as would be due to the pressure of a column of air having the same height and cross section as the chimney, and a density equal to the difference between the density of the rarified air of the chimney and that of the external atmosphere. This pressure will then depend on the vertical height and cross section of the chimney, and the degree of rarification of air within it. The degree of rarification increases with the temperature of the air within the chimney.

The diameter of a chimney is, however, determined by the aggregate cross section of the flues which connect it with the fire, and these are determined by the size of the grate; for, if the chimney have a larger cross section than the flues, the air will then be forced into the fire by a column of air having for its base the aggregate cross section of the flues, and of the density described above, and of the height of the chimney. Thus the diameter of the chimney having been once adapted to the area of the furnace and flues, an increase in the force of draught can only be obtained by an increase of the height of the chimney, or of the temperature of the air within it. †

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* Bartlett's testimony, report, p. 154; Renwick, report, p. 97; Long, report, p. 552; Locke, report, p. 442.

† Renwick's testimony, report, pp. 99, 108, 111; Bartlett, report, p. 159, answer 14; p. 173.

The air does not enter into and pass through the fire and chimney with the force due to the pressure above given; for the fuel opposes considerable resistance to this force; the flues or horizontal passages through which the air and gases are passed after combustion, in order to apply their heat to the surface to be heated, resist this force; and, finally, the friction of the internal sides of the chimney resist it. Much, therefore, of the force with which the air would otherwise be driven into the furnace is spent in overcoming these resistances. These resistances will vary with the nature and depth of the fuel in the furnace, and the length and width of the flues and of the chimney.* The evidence shows that, under all circumstances, a chimney of proper dimensions will furnish sufficient draught for the combustion of *wood* and *bituminous coal*, and, under some circumstances, for the combustion of anthracite coal.† But in consequence of the hard and compact nature of anthracite coal, it ignites with difficulty, and when required to be burned within small limits, and rapidly, the natural draught is found insufficient, and the blower is necessarily resorted to.‡ The fan-blower is an instrument by which air is driven into the furnace by the power of the engine. It consumes a part of the power of the engine, however, and is never required in the combustion of bituminous coal or wood.§

Rightly to investigate the problem of combustion in any particular instance, requires all the above conditions to be considered. It would appear to be true, that the greater the quantity, and the greater the velocity of the air forced through any given mass of heated fuel, the more vigorous would be the combustion and the greater the amount of heat developed by such fuel in a given time.‖ This is undoubtedly true in practice, but while the greatest amount of heat might thus be obtained in a given time from a furnace of any given size, the greatest amount of heat which such fuel could have afforded might not be so obtained; for it will be evident, that while the velocity of the air might be greatly increased, the section through which it would be admitted into the fire through the flues, or into the chimney, might be so small as to allow but a diminished quantity to pass. Combustion would be then imperfect, for unconsumed fuel in the shape of carbonic oxide would be carried off, and much heat might be lost by the amount carried off from the high temperature at which the gases would escape at the top of the chimney. By making the same *furnace flues* and *chimney* broader, and diminishing the velocity and increasing the quantity of air, a greater amount of heat might be obtained from the same fuel in the same time; or, by *occupying a longer time*, and diminishing the velocity of the air, a greater amount of heat might be obtained from the same fuel in the furnace without any such alteration.¶

Where fuel is scarce, it became a question of considerable importance to determine under what conditions combustion could be most *economically* carried on. Careful experiments were tried to solve this problem. Those of Peclet, in France, are best known, and these were brought before the commissioner during the hearing of this cause.**

The results of these experiments established generally, that a slow combustion of fuel thinly spread upon the furnace was the most *economical;* for then the fuel was entirely converted into carbonic acid, and the gases escaped from the top of the chimney at a now temperature, and thus little heat was wasted.

To effect slow combustion, under these circumstances, the proper size of the grate surface of the furnace was determined from the amount of coal to be consumed per hour. The size of grate surface then indicated the size of the flues, and the area of these regulated the diameter of the chimney. Peclet then determined that the air should enter the chimney at a temperature of about six hundred degrees of Fahrenheit, and that the height of chimney should be about thirty feet. It will be remem-

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* Bartlett, report, p. 145; Renwick, report, p. 100.
† Secor, report, p. 190; Renwick, report, p. 100.
‡ Renwick, report, p. 100; Bartlett, report, p. 156.
§ Secor, report, p. 190; Copeland, report, p. 208; Curtis, p. 137, 138.
‖ Renwick, report, pp. 104, 105, 111; Bartlett, report, p. 147.
¶ Renwick, report, p. 111.
** Byrne, report, p. 130.

bered that the object of these experiments was to ascertain how fuel could be most *economically* consumed, without reference to the *size of the furnace*, or to the *time* of consumption. Peclet deduced a mathematical formula from his experiments, which formula is generally considered to be applicable to every problem where an *economical* combustion of fuel is sought for. The problem of *economical* combustion having been thus solved, the best mode of applying the heat so developed to the production of power through the steam engine, then became a subject of careful experiment; and this is generally supposed to have been attained by the Cornish engineers, who adopted large grate surfaces, large boilers, and condensing steam engines.* The general practical result of these experiments may be thus stated: that when fuel is sought to be burned *economically*, combustion should be carried on in large furnaces, the fuel should be kept thin upon the grates, large boilers should be employed, and a moderate draught only should be given. In other words, *where* a large furnace and boilers *can* be employed to obtain a small amount of power, fuel may be economically used, and the draught of a low chimney will suffice.

The experiments of Professor W. R. Johnson, alluded to in the argument, determined, as Peclet had before done, that *a pound* of coal consumed in a furnace with a chimney forty-one feet high, generated more steam than *a pound* of coal did with a chimney sixty-three feet high; but they did *not* determine that the amount of steam which a chimney forty-one feet high would generate in a *given time* was greater than the amount of steam which a chimney sixty-three feet high would generate in the *same time*.†

While we admit the former proposition to be true, we deny that the experiments of any one have ever shown the latter. And although the "chimneys on the western boats may have long since transcended the proper length" for most economically converting 1,722 pounds of coal per hour into one hundred and seventy-two horse-power, they have not transcended the proper length for converting 4,200 pounds of coal per hour into nine hundred horse-power.‡

The above experiments, and the rules deduced from them, have been found extremely serviceable in the construction of furnaces, boilers, and engines on *land*, where neither the size nor the weight of the materials and structures were of any importance in comparison with the saving of fuel.

But the application of either of these experiments fails with regard to steamboats. The main problems to be solved in the construction of steamboats are, first, to give them such forms with regard to length, breadth, depth, and curves, that they may most readily displace the water in sailing; and, second, so to arrange the structures on them, by which the power is developed from the fuel and applied to their propulsion, that the greatest amount of power may be obtained with the least amount of weight and room.§

The consideration of *economical* combustion then became subordinate to that of obtaining on a given boat the greatest propulsive power in the least space and with the least weight. In seeking to attain this end, the various conditions of combustion, and the various modes of using steam-power, have been made, during the last ten years, subjects of experiment and earnest practical study by boat-builders and engineers throughout the world. While pursuing this commen object, the arrangements adopted at different harbors where steamboats have been constructed, have

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*Bartlett, 148.

†It is said in a note on page 88 of the defendants' argument to be a "*stinging satire*," on Professor Renwick's judgment, that he had, on an occasion previous to his giving testimony in this cause, certified that some patented arrangement with a low chimney was "the best application of natural laws to the *economical* combustion of fuel" which had then been exhibited to a committee of the American Institute. The *sting* of the satire falls harmless when it is remembered that an arrangement may be the best for the economical combustion of fuel, and yet by no means the best for the *rapid conversion of fuel into power*; and he who would confound these two objects, might become himself the subject of satire.

‡The former is the amount which Professor Bartlett fixes for economical combustion on a western boat; the latter, the amount which Mr. McAlpine's report shows is actually consumed.

§Howell, report, 176, 177; Secor, report, 187, 189; Renwick, 102; Locke, report, p. 442.

been modified by the fuel which they were severally compelled to employ, the depths of the streams which they navigated, and the risk of storms to which they were exposed.

On marine steamers, where the depth of water occupied was not a matter of so great importance as on river boats, the low pressure boiler and engines have been adopted, and large grate surfaces and furnaces have been employed; the amount of air required for combustion, and the resistance to its passage through the furnace being thus diminished, the force of draft required for such furnaces was small. If they burned bituminous coal or wood, ample draft could be obtained by the chimney; but then they were restrained from carrying it to the elevation required for their purpose by the liability of its exposure to storm. Notwithstanding this risk it has been deemed advantageous, where bituminous coal or wood is used upon the most approved marine steamers of the present day, to depend solely on the draft of a high chimney, rather than resort to mechanical substitutes. Where anthracite coal has been used on marine steamers, inasmuch as the chimney could not be sufficiently elevated to furnish draft, blowers have, of necessity, been adopted. Where it has been optional which fuel should be used, bituminous coal and the chimney draft have been preferred.

In illustration of this, we need only refer to the principal marine steamers which have been recently constructed at New York.

The two Collins' steamers, the Pacific and the Baltic, have chimneys seventy feet high from the flues, and are four feet higher than the highest steamboat chimney at Pittsburg.*

The ocean steamer *North America* is fifty-seven feet above the flues.†

The ocean steamer *Ohio* is sixty-two feet above the flues.‡

The ocean steamer *Georgia* is sixty-two feet above the flues.§

These boats have all been built within two years, and the intelligent engineers and practical men who constructed them, state in evidence that the object of giving them that altitude of chimney, was to get sufficient draft; and the only reason which deterred them from carrying them higher was the inconvenience of taller chimneys to sea steamers.‖ These engineers also inform us that blowers are not necessary to obtain sufficient draft with bituminous coal, and that, while blowers are applied to burn anthracite coal, they always prefer to carry up the chimney on boats which burn bituminous coal, and depend for draft on such high chimneys alone.

On the boats which run through Long Island sound, anthracite coal is used, and it is found indispensable to have blowers, and the chimneys are shortened on this account, and on account of their liability to storms.¶

By the North river boats, steam of higher pressure is used than on the marine steamers, and the boilers and engines are smaller; but, inasmuch as anthracite coal is used, no height of chimney would furnish sufficient draft to burn the quantity of this fuel which they are required to burn; therefore they are compelled to use the blower. Some of these boats, even when the blower is used, have chimneys of the height of fifty-two feet above the flues.**

The steamboats which navigate the Ohio and Mississippi adopt such an arrangement of boiler, engine, and furnace as will occupy the least room and be of the least weight. Accordingly, small high-pressure engines are used, and small cylindrical boilers with furnaces of a corresponding size and weight. Within these contracted limits a vast amount of fuel is to be converted into great propulsive power. To do this in the small furnaces of these boats requires a vigorous combustion and powerful

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* Copeland, report, p. 207.

† Rep. p. 176.

‡ Rep. 186.

§ Rep. 186.

‖ Howell, report, p. 176, 177.

¶ Lasher, report, p. 204.

** Copeland, report, 202; Lasher, report, 204; Bartlett, report, p. 156. Reference is not had here to small ferry and tow-boats alluded to by Curtis and Mason.

draft. The shallowness of the river, and the want of room on these boats, render it of the highest importance that the boilers and machinery should be thus contracted in their dimensions. These boats are compelled to run sometimes in but three feet of water. The fuel consumed is bituminous coal or wood, and the draft furnished by a tall chimney is found in practice to be ample for the conversion of the fuel into power. Experience has shown that the size and speed of these boats may be greatly increased with small additional weight of furnaces and machinery; and that an ample supply of air for the combustion of the fuel necessary to propel them can be obtained by the addition of a few feet to the chimney. On the lake steamers, where bituminous coal or wood is used, the chimneys are carried up, and the natural draft from such chimneys is relied on.*

Having thus explained the general phenomena of combustion and the principles of draft, we would reply more particularly to some of the positions in the printed argument of the defendants.

The first conclusion is, that a diminution of twenty feet in the height of the packet chimneys would not cause a loss of more than five per cent. in the power of the boat, nor a loss of speed of more than two per cent.†

It is attempted to demonstrate this, by showing that inasmuch as the velocity with which the air is forced into the furnace is increased by an increase of the height of chimney, only in proportion to the square root of such increase of height—that, therefore, a fourfold increase of height of chimney gives only a twofold benefit in the combustion of the furnace.

In reply to this, it is submitted that such conclusion is erroneous; is proved not to be true in practice by the testimony of several witnesses—is contrary to the testimony of Professor Bartlett, the only scientific expert examined on behalf of the defendants, and is not attempted to be established as a practical fact by a single witness.

Although an increase in the height of a chimney of a given diameter increases the *velocity* with which the air is forced into the fire only in the proportion of the square root of the height, it is to be remembered that with such increased velocity there goes an increased quantity; and the combustion becomes more vigorous for two reasons: *first*, the quantity of air forced into the furnace in a given time is greater, and therefore the combustion is more rapid; *second*, this rapid combustion elevates the temperature of the air in the chimney and thus increases the pressure by which the external air is forced in; and, except when combustion is to be carried on *economically*, the temperature of the chimney *may* be advantageously increased above 600° Fahrenheit.‡ The temperature of the air in the packet chimneys is shown by the evidence to be sometimes at a red heat, which is above 1,000° Fahrenheit. And it is probable from the exposure to which these pipes are subjected, that the mean temperature would not then much exceed 600°. The French philosopher, intent only on *economy* of fuel, says, if it does escape at a higher temperature than 600°, there is a loss of heat. It is not contended by us that the packets are models of *economical* combustion. They are models of the *rapid* conversion of fuel into power, with economy of *space* and *weight;* the latter being higher considerations *to them* than economy of fuel. The calculations on which the defendants' reasonings are based, are made upon the supposition that coal is burned with a certain degree of rapidity and under certain conditions which are not possible on these packets. The problem of ascertaining the loss of power by a diminution of the height of the chimney on any given boat involves a great number of practical and theoretical considerations, which it is hardly supposed will be again entered upon at this stage of the

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* Johnson, report, p. 224; Secor, report, pp. 186, 190.

† See defendants' argument, pp. 83, 84.

‡ The degree recommended by Peclet as best for *economical* combustion.

cause. These reasonings were submitted to the commissioner by the defendants in the testimony of Professor Bartlett, and during a week of patient investigation on the part of the commissioner, that particular branch of the subject was discussed by the learned professor in the presence of counsel. The numerical calculations alone of Professor Bartlett, occupy many pages of the report; and to the conclusions which the professor drew from those calculations, we cordially join with the defendants in referring the court.* It is respectfully submitted that the defendants' printed argument is an attempt to re-establish positions which have been contradicted by their principal witnesses—have been considered by the commissioner and decided by him to be untenable. And these conclusions appear upon the argument without a shadow of authority in the evidence. They have, indeed, collected detached statements of results, which are stated to be true under one set of conditions, and combined them with results stated to be true under another set of conditions, and they have succeeded in deducing a result which is true under *no possible condition;* they have found no scientific witness to state that a diminution of twenty feet in the height of the packet chimneys would involve, in his opinion, but two per cent. loss of speed.

As to the importance and necessity of high chimneys on these packets, and to the ill consequence of reducing their height, the following testimony of Professor Bartlett is given. It is corroborated by Professors Renwick, Byrne, Long, and Locke, and (if Professor Bartlett may be allowed to judge) by Peclet.†

Professor Bartlett first calculated the amount of fuel which ought to be burned in the furnace of a western packet (the Buckeye State), regard being had to *economy* of combustion.

Ques. 10. "You have given the proper height for the Buckeye State's chimneys, corresponding to their diameter, according to Peclet's formulas, but allowing her to burn only the amount of coal per hour which you deem suitable to her present grate, and allowing that coal to be laid ten inches thick on the grate; now state what would be their proper height, according to the same formulas, allowing her to burn the quantity of coal, and at that depth on the grate which Peclet considers to be the best for evaporating purposes?

Ans. "Peclet takes an example in which the coal was three inches and a fraction in depth upon the grate, and where 20.51 pounds of coal were burnt per hour on each square foot of grate surface, as affording the best evaporating effects. Computing the height of that boat's chimneys from these data, and from the dimensions of the grate, the diameter of the chimney and of the flues, I find the height of the chimney, according to Peclet's formula, to be 30.7 feet above the boilers."—*Bartlett's testimony*, Rep., p. 150.

Professor Bartlett then demonstrates that if they did burn coal thus economically, they would get a power equal only to *one hundred and seventy-two* horse power.

Quest. 24. "You have stated in your examination in chief, in answer to one of the questions, that Peclet takes the example in which coal was three inches and a fraction in depth upon the grate, and where 20.51 pounds of coal were burnt in one hour on each square foot of grate surface, as affording the best evaporating effects; and that computing the height of the chimney required to be given in that answer, according to Peclet's formula, it would be 30.7 feet; please state what horse power you would obtain in that case?"

Ans "As in my last answer, I deduce the horse power from the quantity of coal consumed per hour; which, in the case mentioned in this question, is 1,722.84 pounds Allowing ten pounds to the horse power, will make the whole horse power 172.28. This, as in a former instance, supposes the boiler duly proportioned to this increased amount of fuel, and all other elements, except the grate, duly proportioned to the boiler."—*Bartlett's testimony, Report*, p. 162.

Now it is shown in the engineers' report (p. 706), that the Buckeye State, with its

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*Defendants' argument, p. 95.

†Bartlett's testimony, report, p. 145; Renwick, report, pp. 97, 111; Byrne, report, p. 115; Long, report, p. 553; Locke, report, p. 443.

chimney *sixty-four feet high*, succeeds in burning per hour 4,281 pounds of coal, and obtains a power of *nine hundred and twenty-eight* to thirteen hundred horse power.

From this calculation of the Professor, and the practical fact shown by Mr. McAlpine's report, by adding thirty feet to the height of the chimney, a gain of about six hundred per cent. is obtained in power; and, therefore, a diminution of thirty feet would cause a loss of six hundred per cent. of power, and not about five per cent., as the counsel concludes. The Professor does not think that the increased amount of fuel which is burned on those packets could be so burned without an increase in the height of chimney.

Ques. 25. "Suppose that the dimensions of the Buckeye State were to remain the same as supposed in the last question—that is, grate surface four feet by twenty-one feet, ten flues thirty feet long and eighteen inches in diameter, two chimneys, each five feet six inches in diameter; and suppose the boilers to remain unchanged, and that you were required to burn an increased amount of coal beyond that stated in the last question, in order that you might obtain an increased power; would you not be obliged to increase the height of your chimneys beyond the 30.7 feet stated in the last question?"

Ans. "This question takes for granted that there will be a gain of power by increasing the quantity of fuel consumed in a given time; that such will be the fact in a properly proportioned engine, working under the circumstances supposed by the rules I have before referred to, I have no doubt. But how far this gain of power may be carried by increasing the fuel simply, I cannot venture to say. I should think not very far, with safety. *To increase the fuel consumed, under the restricted circumstances of the question, would certainly require an increased height of chimney.* For it will be remarked that the dimensions of the flues, and their number, are to remain unchanged."

Ques. 25. "Under the conditions of the last question, could the increased consumption of fuel, and the implied increase of power, be obtained without an increase in the height of chimney?"

Ans. "I believe it could not."—*Bartlett's testimony, Report*, p. 163.

Professor Bartlett concludes, therefore, that the packets do not burn coal *economically*, (*Rep.* p. 155, *ans.* 21), but he does not conclude that they had better, therefore, shorten their chimneys, for he says in answer to that very question—

Ques. 45. "Are you not of opinion, from your solution in answer to the fourteenth direct interrogatory, that, supposing the boat therein alluded to (the 'Clipper, No. 2') burned or desired to burn thirty-two bushels of coal per hour on her grate surface as there given, her present chimneys are as short as they ought to be for that purpose, supposing them to be fifty-five feet high above the boilers?"

Ans. "I am of such opinion."—*Bartlett's testimony, Report*, p. 173.

We submit that the above deductions of Professor Bartlett, which is the only scientific evidence the defendants have offered to sustain the *premises* of their argument, are a full and complete refutation of the conclusions attempted to be drawn from the Professor's calculations.

The second position taken is, that the chimneys on the packets might be diminished in height without disadvantage, if their diameter were increased, *i. e.*, that an increase of diameter of chimney would produce an increase of draft as great as an increase of height would produce.*

In the first part of this paper we explained that the diameter of a chimney cannot be advantageously increased much beyond the aggregate of the flue sections, whereas, there is no such limit to the advantageous increase in the height of a chimney. Any beneficial increase in the diameter of a chimney adapted to any particular flue section cannot be made without a corresponding increase of that flue section, a corresponding increase in the size of the furnace and of the boiler. To say, then, that the Western packets ought to enlarge the diameter of their chimneys and make them shorter, is

* Defendants' argument, report, p. 130, 132.

impliedly to say that the whole system of construction of these Western boats must be changed, and that they must all be rebuilt.

To show that a mere increase of diameter of chimney, without an increase of flue section does not produce any benefit except the slight one due to a diminution of friction we quote the opinion of Professor Bartlett, (in which he refers also to Peclet:)

Ques. 14. "Looking at the same formula (Peclet's formula), please state whether D (the diameter of the chimney) can practically be varied to any considerable extent without a corresponding variation in the flue section and grate surface?"

Ans. "In any practical application of this formula, if it were adjusted to a particular case—as one in which there were flues, the sum of the areas of whose cross sections was equal to the sectional area of the chimney—D (the diameter) could not, in my opinion, be varied much, to obtain the corresponding increase of result contemplated by the formula, without increasing the aggregrate cross section of the flues. But that it cannot, does not appear in the formula."—*Bartlett's testimony, Report*, p. 159.

That the beneficial increase of *height* is not so limited appears by the next answer.

Ques. 15. "Is H (the height of the chimney) in any such sense, a dependent variable, practically?"

Ans. "I do not think it is."

Professor Bartlett states, after calculation, that the diameter of the chimneys on the western packets cannot be beneficially increased.

Ques. 44. "Does it appear from any of your calculations, and from the dimensions of any of the western boats which have been supposed by the respondents' counsel, in their questions, that the chimneys alone could be increased in diameter, with any advantage except that due to the diminution of friction?"

Ans. "It does not appear from any calculations that I have made that they could; retaining their other dimensions unchanged."

We have thus shown, we think, from the testimony of the defendants, that the height of the chimneys on these packets cannot be diminished without disadvantage; and that there is no advantage to be derived from increasing the diameter of the chimney alone. We inquire, what is the only method which the defendants' scientific testimony points out by which these chimneys may be diminished in altitude. Professor Bartlett answers:

"The modifications I would propose, therefore, to burn this coal, and to obtain from it all the power due to it, according to the rules I have before detailed, are to increase the *grate surface, and the boilers, and the fire surface, and the dimensions of the chimneys in due proportion.*"—*Bartlett's testimony, Report*, p. 173.

This modification, which is easily expressed in words, if it were attempted to be carried into practice, would require every large steam packet on the Ohio to be rebuilt, require a total change in the system of construction, and would require them to be run at a vastly increased expense of every thing else but of a few pounds of fuel. The science of boat-building would be afloat upon an ocean of experiment and theory, with no other compass than a French formula, and no other chart than the reasonings of a lawyer.

But it is said, "why multiply arguments to prove what the practice of the whole world, except Pittsburg, acknowledge to be true, that chimneys of eighty-five feet high on such boats as can navigate the upper Ohio are nuisances."*

We think that a slight unfairness has been committed in this branch of the argument. The highest packet chimney at Pittsburg, that the commissioner examined, is only sixty-six feet nine inches long. The dimensions of the chimneys on the seven packets are as follows, as appears from the Engineer's report, page 702.

The total length of chimney from top of horizontal flue to top of chimney is,

On the Clipper, No. 2, fifty-seven feet.

On the Brilliant, sixty-two feet.

On the Keystone State, sixty-four feet.

On the Buckeye State, sixty-four feet eight inches.

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* Defendants' argument, p. 98.

On the Messenger, sixty-four feet three inches.
On the Cincinnati, sixty-six feet nine inches.
On the Hibernia, No. 2, fifty-five feet six inches.

With this correction we, too, are ready to decide the question by the most enlightened practice of the world.

As to the size or fleetness of the London and Gravesend boats, cited in defendants' argument, we confess ourselves ignorant; it is not in evidence whether they are ferry-boats or steam ships.*

It is true that one hundred and thirty steamboats run from New York; and it is true that a number of them have chimneys from fifty-three to sixty feet above the flues, as the Illinois, the New World, the Vanderbilt, the Isaac Newton and several others. It is to be remembered, that with the exception of tow and ferry-boats, none of these boats depend on the natural draft for their supply of air, but upon blowers. Now the height of chimney which a boat *without* a blower might require, can hardly be argued from the height of chimney that any number of boats *with* blowers require. But, surely, if the large New York boats have chimneys fifty to fifty-five feet above the flues, and yet have to use blowers, it is not so unreasonable in the packet-boat builders to add from five to ten feet to their chimneys (which is all the difference), if by so doing they can dispense with blowers. The New York boats could not by any practical height of chimney alone burn *anthracite* coal as they are compelled to do. The same remarks will apply to the Philadelphia boats. It is stated that the *great ocean* steamers obtain abundant draft without resorting to chimneys as high as those on the Pittsburg packets. It must have been forgotten that the Collins' steamers, the Pacific and Baltic, have chimneys sixty-eight to seventy feet from the return flues; these are, therefore, from two to four feet higher than the highest Pittsburg packet chimneys, and from twelve to fourteen feet higher than the two smallest of the seven packet chimneys. The two ocean steamers, the Ohio and the Georgia, have chimneys sixty-two feet high from the return flues, which is as high as three of the seven Pittsburg packet chimneys, and but two feet lower than three others. The ocean steamer North America has a chimney fifty-seven and a half feet high from the flues, as high as two of the seven Pittsburg packet chimneys, and a United States steamer has been recently finished at Philadelphia with chimneys of about the same height.†

The builders of the Pacific and Baltic state that they would have made the chimneys higher, but for the risks of the sea.

On the Ohio and Mississippi there are the Peytona, sixty-three feet high from the return flues; the Hoosier State, fifty-six and a half feet; "Telegraph, No. 2," seventy feet; and the Ben Franklin seventy feet; the Bostona is seventy-seven feet from the flues; the Alexander Scott seventy-six; the Magnolia seventy-eight, besides others. These are as high and even *higher* than the seven Pittsburg packet chimneys.‡

On the lakes, even where they are exposed to storms, are steamers having chimneys from fifty-two to fifty-five feet high above the flues.§

We think that the above instances afford a sufficient answer to the inquiry, "where then in the world, shall we seek for a precedent to justify stacks eighty-five feet high on such boats as the Pittsburg packets?" Provided the palpable error be corrected of calling chimneys which do not exceed in vertical length sixty-six feet, "stacks eighty-five feet high."‖

The placing of a chimney of a given length on any elevation, does not make it a higher stack, nor affect its draft. We respectfully submit that chimneys of the height of those on the western packets are *not* "condemned by the most intelligent and skilful builders in Philadelphia, Cincinnati, Louisville and New York," if the naval en-

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* Defendants' argument, p. 98.
† Secor, report, p. 186; Howell, report, p. 176.
‡ McAlpine's report, p. 702.
§ Secor, report, p. 186.
‖ Defendants' argument, p. 101.

gineer of the Collins' line at New York—the United States constructor at Philadelphia, and the builders of the largest steamers at Louisville and Cincinnati belong to that class.

Having already shown that Professor Bartlett, their own witness, does not support them, we now turn our attention to Peclet. The defendants' argument boldly cites Peclet to prove their several positions; here again we are ready to leave the case to the decision of Peclet. All the passages cited from his treatise in their argument, relate to the chimneys of habitations and factories, or to the economical combustion of fuel. We now refer to the general principles of draft prescribed by that author, and the application of them to *steamboats*. He says:

§ 388. "The *height* of chimney has a great influence on the effect it will produce." * * * * * * * "But in the most ordinary cases, the influence of the height of the chimney is very great in consequence of the resistance of the fuel."

§ 391. "There is really but a *single case* where the height of chimney is without sensible influence; it is where the whole passage traversed by the heated air is reduced to the chimney."

§ 392. "We ought to give to the chimney the *greatest possible* height. We obtain thus a powerful element of draft, which only involves a small additional expense, and which is often of great utility."

§ 386. "Apparatus for heating vary in *form* and *arrangement*, not only with the effect we desire to produce, but also with the *nature of the fuel* employed; and whether we desire to use only the radiated heat from the fire or only that conveyed by the heated air, or both."

"The temperature of the air of the chimney depends on the temperature of the air as it escapes from the fire, the cooling of the air by the surface to be heated, and, finally, by the cooling of the air in the chimney. These causes are so complicated, and depend on so great a number of circumstances, that it is really impossible to calculate the influence and determine the temperature of the smoke in any given establishment, at least with sufficient approximation."

§ 666. "*Fires in which the combustion is produced by currents of great velocity.*—In the fires in question, the air is supplied by large and *high* chimneys, or by machines. These fires have always for their object to produce in a mass of fuel a very high temperature. They are always fed by combustibles which burn *without flame*, and the depth of the fuel is very great."

§ 722. "When boilers are to generate steam of a low pressure, they may have any desired form, provided they have sufficient stays to resist the pressure of the steam." * * * * * "When the steam is used at a high pressure, they always employ cylindrical boilers with exterior flues." * * * * "Finally, in steamboats and locomotives they employ *peculiar arrangements*, required by the circumstances in which these machines are obliged to work." * * *

And with regard to the substitution of economical fixtures for natural draft cited in defendants' argument, p. 143, he says:

§ 1062, 1063. "By the improvements which we have indicated for boilers and fires, the useful effect in the majority of steam boilers may be increased two-fold, for the loss of steam occasioned by the different modes of artificial draft is small." "With the boilers of steamboats, it must not be expected to utilize entirely the heat developed by the arrangements of which we have spoken, because of the very *small space* in which these boilers must be placed." * * * *

§ 1064. "Another improvement not less useful for steamboats, consists in a good arrangement of boilers; for all those which are employed have great inconveniences, either from their small *strength, from their weight*, from the too great space which they occupy, or from the difficulty of cleaning them. The problem is more difficult to solve than for *stationary* boilers, since there are *many* conditions to be fulfilled; but it is a subject of great *importance* and deserves the attention of engineers." * * * *

"The boilers of Mr. Perkins satisfy probably more of the conditions than any others used. * * * * There might be given to boilers a cylindrical form, which would occupy less space and be stronger." * * * * "But it is important to determine if all fuels, and particularly *bituminous coal*, can be employed with as much advantage as coke, which has been exclusively used for this mode of heating; *and whether, by increasing the height of the circuit* (*chimney*), *and consequently the velocity* of circulation, it may not be possible to produce the same useful effect with a less extent in the two kinds of heating surface."

The report of Mr. Roebling, made in 1845, *recommending a bridge*, did contain a scientific prophecy, "that the time would come when there would be no high chimneys." The simple answer to that is, that the time does not appear to have yet arrived; for their height has been constantly increasing since the date of the prophecy up to the present time.*

With regard to the application of fan-blowers, instead of chimney draft, the posi-

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*Defendants' argument, p. 109.

tion of the navigators of the Ohio is clear. The packet builders and owners consider that, since by simply adding from five to ten feet to the height of their chimneys, all the required purposes of draft can be met, it would be extremely inconvenient and expensive to be obliged to use blowers. On the eastern waters, where anthacite coal is used, they are compelled to employ them by the nature of the fuel, but with bituminous coal or wood, they are never necessary. Anthracite coal is of a hard, compact nature, and burns with a short flame; bituminous coal and wood burn more easily, and with a long flame. Anthracite coal does not heat the air of the chimney as much as bituminous coal, and is therefore incapable of supporting as good a natural draft, while it requires for its combustion a stronger draft. The strongest proof of their inapplicability to the consumption of bituminous coal is found in the fact, that while they are almost universally used with *anthracite coal* to the east, they are never used with *bituminous coal*, either at New York, Philadelphia, on the Lakes, or on the Ohio. And the defendants have succeeded in producing but one witness who *uses* them with bituminous coal. The scientific experts, Professors Renwick and Bartlett, and the most intelligent practical experts, state that blowers are an incident to the combustion of anthracite coal, arising from the nature of that fuel. They were never introduced into boats, until anthracite coal was used there, and they have never extended beyond the region where anthracite coal is employed. These facts are true, as well of the use of the blower with land as with marine engines. Their destructive effects on the boilers, their increased expense, and the fact that they are entirely unnecessary for bituminous coal and wood, are, we submit, conclusive objections to their substitution for tall chimneys where these fuels are burned. The utility and applicability to these boats, of blowers, was a subject of careful examination before the commissioner, and he deemed them worthy of but a passing remark.*

The defendants' argument points out many defects in the construction of the western boats, boilers, and chimneys, and suggests a great number of changes by which the chimneys may be shortened, and the boats otherwise improved.

Many similar suggestions were made to the commissioner by the defendants' witnesses; the packet builders will doubtless appreciate them properly. One witness said the chimneys should be lowered, and their diameter increased.† A second witness said that will not do, unless they make their furnaces and boilers larger; their grate surface should be increased from one hundred and forty-four square feet of area, to over one thousand square feet of area.‡ A third said they should let down their chimney by a hinge.§ A fourth said it should be done by a slide.‖ A fifth said they should use blowers.¶ A sixth said they should use steam jets.** Finally, a witness came who was "familiar with furnace stacks and draft generally," was "familiar with almost all the different kinds of chimneys, &c., for the purpose of draft on steamboats;" he said height of chimney is of *no importance* whatever; they should have *a patent fuel saving apparatus*, which can be used by paying a tax to the inventor of *one hundred dollars* for every ten horse power. By this machine, all the fuel is converted into *liquid carbonic acid, and falls down in the liquid state on the hearth, and mingles with the ashes!*††

If these defects do exist, they are the consequence of very wide spread error; for the same general principles of construction are followed throughout the United States, and will probably continue to be followed until obstructions to commerce on navigable rivers are so multiplied as to enforce the reforms suggested in the argument. One thing is certain: the discovery of these defects, though of long standing, was not made until after the date of the Wheeling bridge.

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* Bartlett, report, p. 150; Renwick, p. 100; Byrne, p. 116; Curtis, p. 137, 138; Johnson, p. 225; Secor, p. 190; Howell, p. 185; Copeland, p. 207; Locke, report, p. 445.

† Stewart, report, 3, 531, 532.

‡ Bartlett, report, p. 174.

§ Mason, report, p. 407.

‖ Record, p. 333.

¶ Parry, Record, p. 306.

** Loper, Record, 311.

†† Harvey, report, p. 211.

It is respectfully submitted that the following points are supported by the evidence returned to this court by the commissioner.

1. That scientific principles as expounded by Professors Bartlett, Renwick, Locke, Byrne, and Long, establish that height of chimney has a most important effect on the draught of furnaces and rapidity of combustion.

2. That whatever may be the limit to which the height of chimney may be theoretically carried to increase combustion, in practice, that limit has not yet been attained on any western steam packet.

3. That the diameter of the chimney is limited by the size of the furnace and flues, and therefore cannot be beneficially increased.

4. That the exigencies of navigation compel the adoption, by the western packets, of a contracted arrangement of flues and boilers; and the conversion of the fuel into sufficient power under such circumstances demands a rapid combustion.

5. That the height of chimneys on these packets is not greater than they require; and that these high chimneys furnish the only proper mode of procuring draft for them.

6. That while anthracite coal is adapted to the use of the blower and oftentimes need it—bituminous coal and wood are not adapted to and never require it.

7. That the testimony of practical engineers and boat builders shows that the foregoing scientific principles are confirmed in practice; and that the high chimneys of the western packets are sanctioned by the experience of other places.

We have thus endeavored to sustain the position taken by the commissioner in regard to the utility and necessity of tall chimneys on the western packets. The determination of the question involved a multitude of considerations which could not properly have been introduced into the commissioner's report; the complexity of the subject was inherent in its nature. To investigate what was a proper height of chimney for packets on the western rivers, using bituminous coal, and drawing three feet water, by the aid of the opinion of professors of science based on laboratory experiments—the opinions of marine engineers whose boats drew fifteen and twenty feet of water—and the opinion of engineers using anthracite coal and blowers, was no easy task. The difficulty of reconciling opinions varying as these did, was enhanced by the unusual absence of scientific treatise in reference to this particular subject. The only book relied on to any extent was Peclet's Treatise on Heat, which was written in 1828, and re-published in 1843. The American steamers cited by that author have passed away, and their names have been forgotten. Within the last ten years the Collins and Cunard steamers commenced to traverse the oceans; the North river and Long Island sound boats have doubled their speed and dimension, and the mighty packet steamers of the lakes and Ohio river have sprung into existence. At the present hour these river steamers are regarded by Europeans as one of the wonders of this continent. These boats do not owe their form, size, or power, to scientific formulas or books; they have been produced by gradual improvement, worked out by practical men contending against natural difficulties of navigation unparalleled in the world—by men whose reputation, fortune and lives depended on the manner in which they constructed their boats.

In the determination of a question of fact so difficult, the propriety of the course pursued by the Court in referring it to a commissioner occupying so exalted a position as Chancellor Walworth, must be evident. The manner in which the commissioner has discharged his duties should, we respectfully submit, give to this branch of his report great weight.

He visited the eastern cities and examined their boats. He listened to the lectures of learned professors called by the respective parties; in one instance, a single professor occupied the stand during six entire days. No evidence was received unless the witness was produced before him. He examined the most intelligent practical experts that the East could produce. He visited the cities of the West; examined scientific and practical experts at all the large towns on the Ohio. He traversed the Ohio river in steamboats, from its head to the Falls. He inspected the packets, their boilers, engines, and flues; conversed with those who used blowers and those who used natural draft.

It is hard to conceive how any one who attended him as he toiled over this subject month after month could do else than testify to the patience, fidelity, and ability with which he discharged the duty imposed on him.

The whole proceeding was one long argument. Could there be more powerful arguments on the scientific principles of the subject than were given by Professors Renwick, Bartlett, Locke, and Col. Long? Could there be more powerful arguments on the practical application of those principles than the testimony of Copeland, Howell, Nelson, Miller, and Thomson? On a question like this, the *facts* are the argument. We venture to add that the amount and value of scientific and practical information contained in the proofs and digested in the report returned by the commissioner to this Court, will make that document the highest standard of reference for professors, engineers, and practical mechanics in the land. Each year's experience, also, and every new boat that will be built, will serve to confirm the conclusion that the natural draft obtained by high chimneys is the best method of obtaining the power by which commerce is transported on the western rivers.